# BALLISTIC WINDS STUDY

## QUARTERLY REPORT

BY

FREDERICK P. OSTBY, JR.

## APRIL 1968

# ECOM

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BALLISTIC WINDS STUDY

Quarterly Report

Report No. 2

1 June 1967 to 31 August 1967

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Prepared by

Frederick P. Ostby, Jr.

THE TRAVELERS RESEARCH CENTER, INC.

250 Constitution Plaza          Hartford, Connecticut 06103

For

U.S. ARMY ELECTRONICS COMMAND, FORT MONMOUTH, N.J.

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# ABSTRACT

Space and time variability studies were conducted for the 12-rawin station mesonetwork of southeastern Arizona.

The space variability studies showed that for low levels (below 1000 meters) there was only a slight increase in variability as a function of station separation. The root-mean square space difference of the vector wind (RMSSD) is 8.0 knots for stations within 20 km of each other, while the RMSSD is 9.6 knots for stations 120—140 km apart. At high levels (e.g., 8000 m) the variability difference with distance is sizeable.

Investigations of time variability indicated the increase in variability with increasing time lag is less at low levels than at high levels. At low levels (around 1000 m) there is not much difference between a 2-hr old observation and one that is 8 hours old. At about 8,000 meters, the variability increases markedly with increasing time lag. From time variability profiles this is seen to be the level of maximum time variability for all lags with the variability diminishing rapidly with height thereafter.

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## 1.0   INTRODUCTION

This report describes technical progress during the second quarter, June 1, 1967 through August 31, 1967 of the contract year, under Contract DAAB07-67-C2967 "Ballistic Winds Techniques Stu..."

Primary emphasis during the quarter concentrated on Task 2, Ballistic Winds Evaluation, concerned with space and time variability studies based on station data.

## 2.0  SPACE AND TIME VARIABILITY STUDIES

In both the space and time variability studies, zone winds were employed rather than the integrated or ballistic wind. This was done to permit examination of the characteristics of individual zones. The zones are non-uniform in thickness which should be kept in mind when considering the relationship of variability with altitude. Also worthy of note is that the wind differences which have been computed include instrumental errors as well as atmospheric variations and hence represent estimates of wind variability.

### 2.1  Space Variability

Wind component differences between every station pair in the 12 station rawinsonde network were computed for all 80 observation times for artillery zones 1 through 12. Root-mean square wind component differences [ $\sigma(u_s)$, $\sigma(v_s)$ ] and vector differences [ $\sigma(V_s)$ ] were computed by the following:

$$\sigma(u_s) = \left[ 1/N \sum_1^N (u_i - u_j)^2 \right]^{1/2}$$

$$\sigma(v_s) = \left[ 1/N \sum_1^N (v_i - v_j)^2 \right]^{1/2}$$

$$\sigma(V_s) = \left[ 1/N \sum \left\{ (u_i - u_j)^2 + (v_i - v_j)^2 \right\} \right]^{1/2}$$

where the subscripts i, j refer to a pair of station locations for which differences are summed over N cases.

Table 1 lists the station pairs, distances between stations, and number of observations for which differences were computed. Because of missing data situations the maximum possible number of observations (80) was never realized.

The space variability was computed by averaging RMS vector difference values for 20-km intervals of station separation: 0—20 km, 20—40 km, etc. The results are shown in Fig. 1. For zone 1, the variability increases only slightly with increasing station spacing. The average variability for the 0—20 km range is 7.9 knots while for station spacing of 120—140 km the variability is 9.6 knots. On the other hand, the range of variability for some of the higher zones is substantial. At zone 10 the variability is 6.3 knots for a station separation of 0—20 km while the variability for stations

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# TABLE 1
## STATION PAIRS, DISTANCES, AND NUMBERS OF OBSERVATIONS

| Station pair | Distance kilometers | Number of observations per zone | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| FR—HU | 16.57 | 61 | 64 | 63 | 64 | 64 | 63 | 62 | 61 | 59 | 51 | 47 | 45 | 703 |
| NO—PA | 17.09 | 60 | 72 | 72 | 72 | 72 | 73 | 73 | 70 | 70 | 70 | 64 | 60 | 838 |
| PA—SO | 17.10 | 66 | 67 | 68 | 68 | 68 | 67 | 67 | 67 | 65 | 64 | 61 | 56 | 784 |
| HU—PR | 20.49 | 68 | 76 | 70 | 71 | 70 | 69 | 67 | 66 | 63 | 56 | 50 | 46 | 766 |
| BI—HR | 21.79 | 59 | 59 | 60 | 60 | 60 | 59 | 58 | 56 | 56 | 56 | 52 | 47 | 682 |
| FR—TM | 25.09 | 64 | 67 | 66 | 66 | 66 | 65 | 64 | 64 | 63 | 63 | 62 | 50 | 760 |
| BE—FR | 26.77 | 62 | 64 | 63 | 62 | 61 | 61 | 61 | 61 | 61 | 59 | 55 | 48 | 718 |
| HR—TM | 27.36 | 71 | 72 | 73 | 73 | 73 | 72 | 71 | 70 | 69 | 69 | 62 | 55 | 830 |
| HR—HU | 28.82 | 67 | 69 | 70 | 71 | 71 | 70 | 69 | 67 | 63 | 57 | 50 | 49 | 773 |
| HU—SO | 31.41 | 64 | 67 | 68 | 69 | 69 | 67 | 66 | 65 | 60 | 53 | 50 | 46 | 744 |
| HU—TM | 31.78 | 70 | 73 | 74 | 74 | 74 | 72 | 70 | 69 | 64 | 58 | 53 | 48 | 799 |
| HR—PR | 32.57 | 68 | 68 | 69 | 69 | 69 | 69 | 69 | 68 | 67 | 67 | 60 | 56 | 799 |
| PA—PR | 33.06 | 71 | 71 | 72 | 72 | 71 | 71 | 70 | 70 | 70 | 70 | 61 | 57 | 826 |
| NO—SO | 34.18 | 62 | 65 | 65 | 65 | 65 | 65 | 65 | 62 | 60 | 58 | 58 | 53 | 743 |
| BI—DC | 34.25 | 54 | 54 | 53 | 54 | 54 | 52 | 51 | 50 | 48 | 42 | 35 | 31 | 578 |
| FR—SO | 35.57 | 56 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 58 | 56 | 57 | 54 | 694 |
| PR—SO | 35.69 | 63 | 64 | 65 | 65 | 64 | 63 | 63 | 63 | 61 | 59 | 55 | 50 | 735 |
| BI—TM | 36.57 | 62 | 62 | 62 | 62 | 62 | 60 | 59 | 57 | 57 | 57 | 52 | 46 | 698 |
| FR—HR | 36.76 | 61 | 63 | 63 | 63 | 63 | 63 | 63 | 63 | 62 | 62 | 57 | 57 | 740 |
| FR—PR | 37.02 | 61 | 63 | 62 | 62 | 61 | 61 | 60 | 60 | 60 | 60 | 53 | 49 | 712 |
| HU—PA | 38.72 | 70 | 72 | 73 | 74 | 74 | 73 | 72 | 71 | 67 | 61 | 53 | 51 | 811 |
| NO—PR | 38.90 | 68 | 69 | 68 | 68 | 67 | 68 | 68 | 65 | 65 | 65 | 58 | 56 | 785 |
| BE—TM | 39.20 | 71 | 72 | 72 | 71 | 70 | 69 | 68 | 67 | 66 | 64 | 60 | 50 | 800 |
| BE—HU | 42.98 | 67 | 68 | 68 | 68 | 67 | 67 | 67 | 65 | 62 | 55 | 49 | 45 | 748 |
| BE—WI | 46.87 | 62 | 63 | 64 | 63 | 62 | 62 | 62 | 61 | 61 | 60 | 54 | 46 | 720 |
| FR—PA | 48.30 | 64 | 66 | 66 | 66 | 66 | 66 | 66 | 66 | 66 | 66 | 62 | 58 | 778 |
| PR—TM | 48.34 | 71 | 72 | 72 | 72 | 71 | 70 | 68 | 68 | 67 | 67 | 59 | 51 | 808 |
| BE—SO | 48.94 | 62 | 63 | 64 | 63 | 62 | 61 | 61 | 60 | 58 | 56 | 52 | 46 | 708 |
| BI—HU | 50.15 | 59 | 60 | 59 | 60 | 60 | 57 | 55 | 54 | 50 | 46 | 42 | 38 | 640 |
| HU—NO | 51.16 | 66 | 71 | 69 | 70 | 70 | 70 | 69 | 65 | 63 | 56 | 52 | 49 | 769 |
| BI—PR | 53.33 | 59 | 59 | 59 | 59 | 58 | 56 | 54 | 54 | 54 | 54 | 49 | 42 | 657 |
| BI—FR | 55.01 | 53 | 55 | 54 | 54 | 54 | 53 | 52 | 51 | 51 | 51 | 46 | 41 | 615 |
| DC—HR | 55.53 | 63 | 63 | 63 | 64 | 64 | 64 | 64 | 63 | 58 | 50 | 37 | 33 | 686 |
| SO—TM | 59.70 | 67 | 68 | 69 | 69 | 69 | 67 | 66 | 66 | 63 | 61 | 60 | 50 | 775 |
| HR—SO | 59.70 | 63 | 64 | 66 | 66 | 66 | 65 | 65 | 64 | 61 | 60 | 57 | 54 | 751 |
| DC—TM | 60.08 | 67 | 68 | 67 | 68 | 68 | 67 | 66 | 66 | 59 | 52 | 40 | 35 | 723 |

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TABLE 1 (Continued)

| Station pair | Distance kilometers | Number of observations per zone | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| BE—HR | 60.87 | 67 | 67 | 68 | 67 | 66 | 66 | 66 | 64 | 63 | 62 | 52 | 49 | 757 |
| BE—PR | 62.97 | 68 | 68 | 68 | 67 | 65 | 65 | 64 | 63 | 63 | 62 | 51 | 47 | 751 |
| FR—NO | 63.27 | 61 | 64 | 62 | 62 | 62 | 63 | 63 | 61 | 61 | 61 | 58 | 54 | 732 |
| HR—PA | 63.40 | 71 | 71 | 73 | 73 | 73 | 73 | 73 | 72 | 71 | 71 | 63 | 63 | 847 |
| TM—WI | 64.68 | 65 | 68 | 69 | 69 | 69 | 69 | 68 | 67 | 66 | 65 | 61 | 49 | 785 |
| BE—PA | 65.41 | 71 | 71 | 72 | 71 | 70 | 70 | 70 | 69 | 69 | 67 | 61 | 54 | 815 |
| FR—WI | 68.77 | 58 | 60 | 60 | 60 | 60 | 60 | 60 | 59 | 59 | 59 | 57 | 51 | 713 |
| PA—TM | 70.07 | 74 | 75 | 76 | 76 | 76 | 75 | 74 | 74 | 73 | 73 | 67 | 56 | 869 |
| HR—NO | 71.43 | 68 | 70 | 70 | 70 | 70 | 71 | 71 | 67 | 66 | 66 | 60 | 59 | 808 |
| BE—BI | 75.34 | 58 | 58 | 58 | 57 | 56 | 54 | 53 | 51 | 51 | 49 | 44 | 39 | 628 |
| BI—SO | 81.35 | 55 | 56 | 56 | 56 | 56 | 54 | 53 | 53 | 53 | 51 | 49 | 43 | 635 |
| BE—NO | 82.19 | 66 | 68 | 67 | 66 | 65 | 66 | 66 | 63 | 63 | 63 | 56 | 51 | 760 |
| DG—HU | 82.51 | 62 | 64 | 63 | 65 | 65 | 64 | 63 | 62 | 55 | 43 | 35 | 30 | 671 |
| NO—TM | 82.92 | 70 | 73 | 72 | 72 | 72 | 72 | 71 | 68 | 67 | 67 | 62 | 56 | 822 |
| DG—FR | 83.64 | 60 | 62 | 60 | 61 | 61 | 61 | 61 | 61 | 55 | 48 | 37 | 34 | 661 |
| HU—WI | 85.03 | 63 | 67 | 68 | 69 | 69 | 68 | 67 | 65 | 64 | 57 | 52 | 46 | 755 |
| BI—PA | 85.04 | 61 | 61 | 62 | 62 | 62 | 60 | 59 | 58 | 58 | 58 | 52 | 46 | 699 |
| DG—PR | 87.57 | 64 | 64 | 33 | 64 | 63 | 63 | 62 | 62 | 59 | 52 | 40 | 35 | 691 |
| HR—WI | 92.02 | 63 | 65 | 67 | 67 | 67 | 67 | 67 | 65 | 64 | 63 | 58 | 53 | 766 |
| BI—NO | 92.14 | 58 | 59 | 58 | 58 | 58 | 57 | 56 | 52 | 52 | 52 | 49 | 44 | 653 |
| SO—WI | 95.80 | 60 | 63 | 65 | 65 | 65 | 64 | 64 | 64 | 62 | 59 | 58 | 50 | 739 |
| BI—WI | 97.22 | 55 | 57 | 58 | 58 | 58 | 56 | 55 | 53 | 53 | 52 | 48 | 40 | 643 |
| BE—DG | 98.03 | 64 | 64 | 63 | 63 | 62 | 62 | 62 | 61 | 55 | 47 | 36 | 32 | 671 |
| PR—WI | 105.46 | 62 | 64 | 65 | 65 | 64 | 64 | 64 | 63 | 63 | 62 | 56 | 51 | 743 |
| DG—WI | 105.47 | 58 | 59 | 60 | 60 | 60 | 60 | 60 | 59 | 55 | 48 | 38 | 34 | 651 |
| PA—WI | 112.24 | 66 | 67 | 69 | 69 | 69 | 69 | 69 | 68 | 68 | 67 | 61 | 54 | 796 |
| DG—SO | 113.91 | 58 | 59 | 59 | 60 | 60 | 59 | 59 | 59 | 34 | 45 | 36 | 32 | 650 |
| DG—PA | 118.92 | 66 | 66 | 66 | 67 | 67 | 67 | 67 | 67 | 61 | 53 | 40 | 36 | 723 |
| DG—NO | 126.39 | 63 | 65 | 64 | 64 | 64 | 65 | 65 | 62 | 57 | 51 | 41 | 37 | 698 |
| NO—WI | 128.91 | 64 | 67 | 67 | 67 | 67 | 68 | 68 | 64 | 64 | 63 | 60 | 53 | 772 |

BE—Benson
BI—Bisbee
DG—Douglas
FR—Fairbanks

HR—Hereford
HU—Ft. Huachuca
NO—Nogales
PA—Patagonia

PR—Parker Canyon
SO—Sonoita
TM—Tombstone
WI—Wilcox

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120—140 km apart is 14.6 knots. Thus, in terms of exterior ballistics, it can be seen that for low elevation firings, say up to line 3, there is not much to be gained from decreasing the station spacing, but for high elevation firings, such as line 10, there is a sizeable potential reduction in variability when the spacing between stations is decreased.

It is interesting to consider space variability as a function of altitude. For all station separations, there is a general decrease in variability with altitude starting from zone 1 to the middle zones, followed by an increase reaching a maximum around zone 11. Above zone 11 the variability decreases markedly.

The level of minimum space variability appears to be somewhat dependent on station separation. For stations within 60 km of each other, the level of minimum variability is zone 6 (2000—3000 m) while for stations farther apart, 60—140 km, the minimum is at zone 3 (500—1000 m).

The maximum variability at zone 11 (8000—10000 m) is near the level of maximum winds. Above zone 11 the space variability is much less, even though the westerly winds are still strong.

The fact that the space variability is larger at zone 1 than the middle zones is probably due to small-scale effects, part of which are undoubtably due to terrain.

For stations close together (within 40 km), the maximum variability is at zone 1 with the secondary maximum, of lesser magnitude, at zone 11. For stations farther apart, the zone 11 maximum is considerably larger than the zone 1 variability. These differences are reasonable since stations close together would be expected to be influenced more by low-level small-scale variations than upper-level large-scale variations. For stations with greater separation, the reverse would be expected.

## 2.2 Time Variability

Time variability statistics for both u and v components and vector differences were computed for each station for lags of 2, 4, 6 and 8 hr. The basic variability measure is the root-mean square time difference $\sigma(V_t)$.

$$\sigma(V_t) = \left[ \frac{1}{N} \sum (u_{t_1} - u_{t_2})^2 + (v_{t_1} - v_{t_2})^2 \right]^{1/2}$$

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where the subscripts $t_1$, $t_2$ refer to different pairs of observation times at the same station for which differences are summed over N cases. Figure 2 shows the time variability as a function of altitude and lag for a composite of all 12 stations. The outstanding features are the general decrease in variability with altitude, up to around zone 3, followed by an increase to zone 6, little change to zone 8, followed by an increase to zone 10, the level of maximum variability. Above zone 10 the time variability decreases with altitude.

Figures 3 through 14 show the time variability by individual stations. Several of the stations exhibit an apparent decrease in variability with altitude between zones 7 and 8: Benson, Bisbee Junction, Hereford (between zones 6 and 7), and Wilcox. However, the number of cases is too small to show that the differences are significant.

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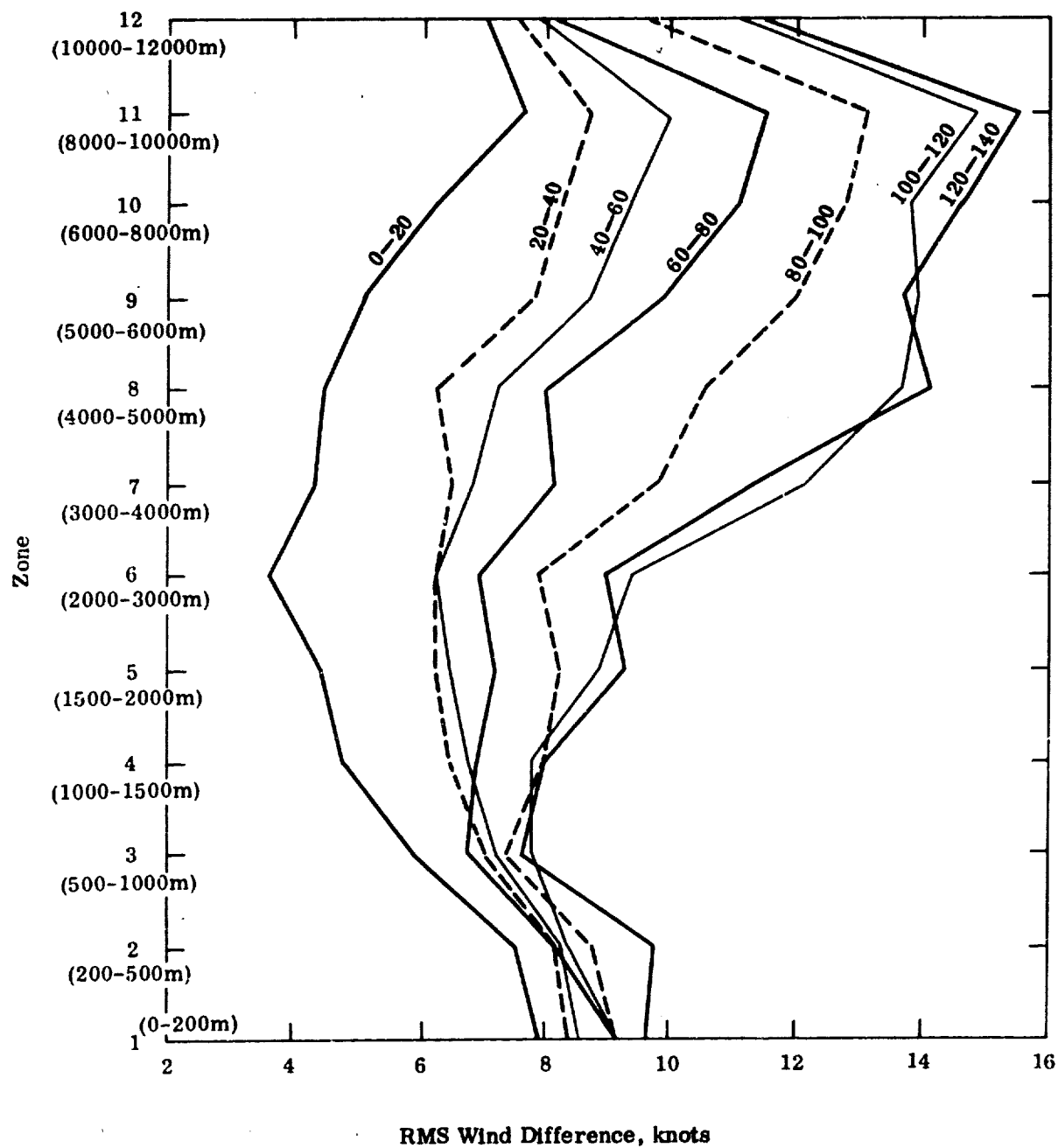
Fig. 1. Averaged RMSWD values for 20-km intervals of station spacing. all stations.
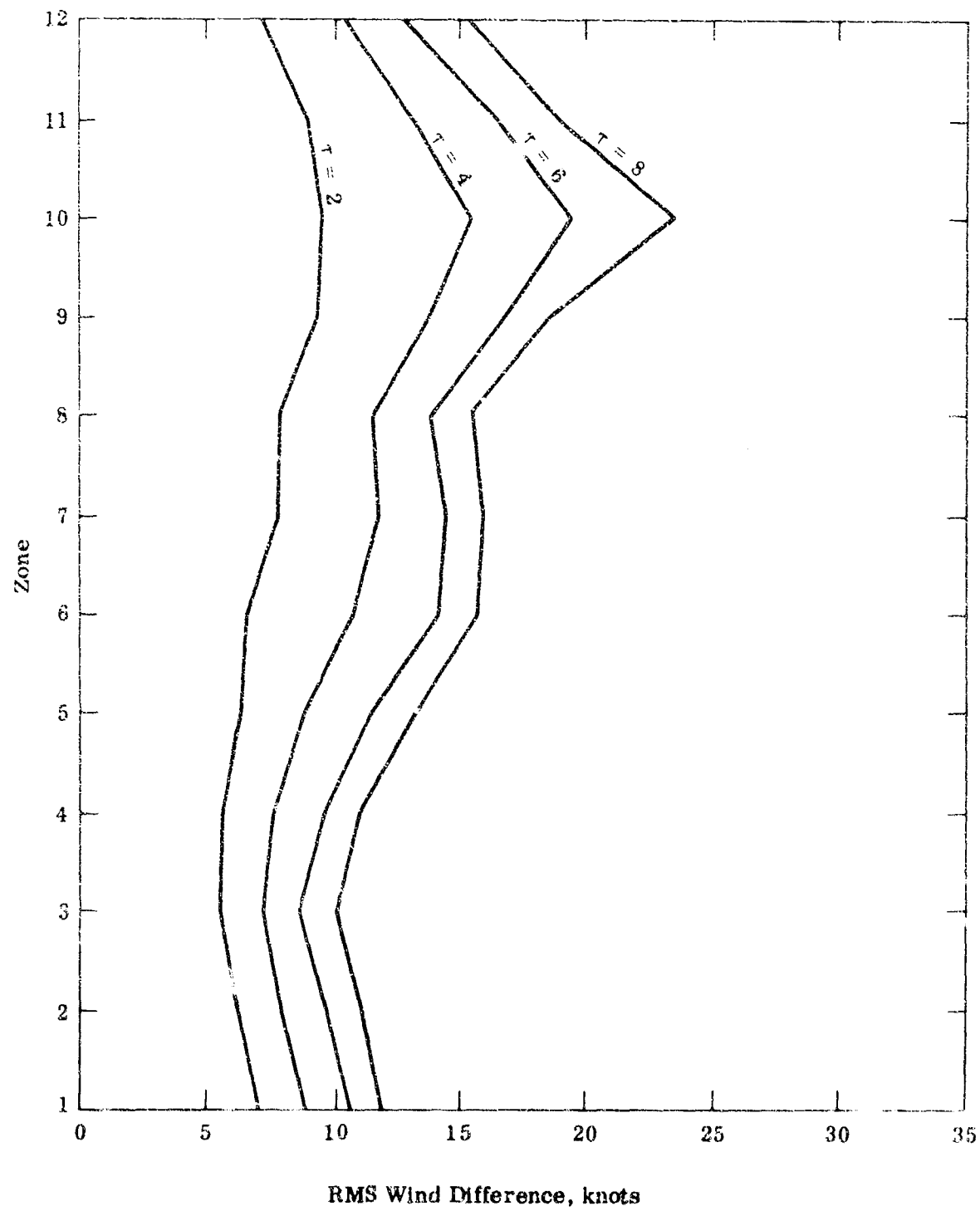
Fig. 2. Composite of time variability as a function of altitude and lag, all stations.
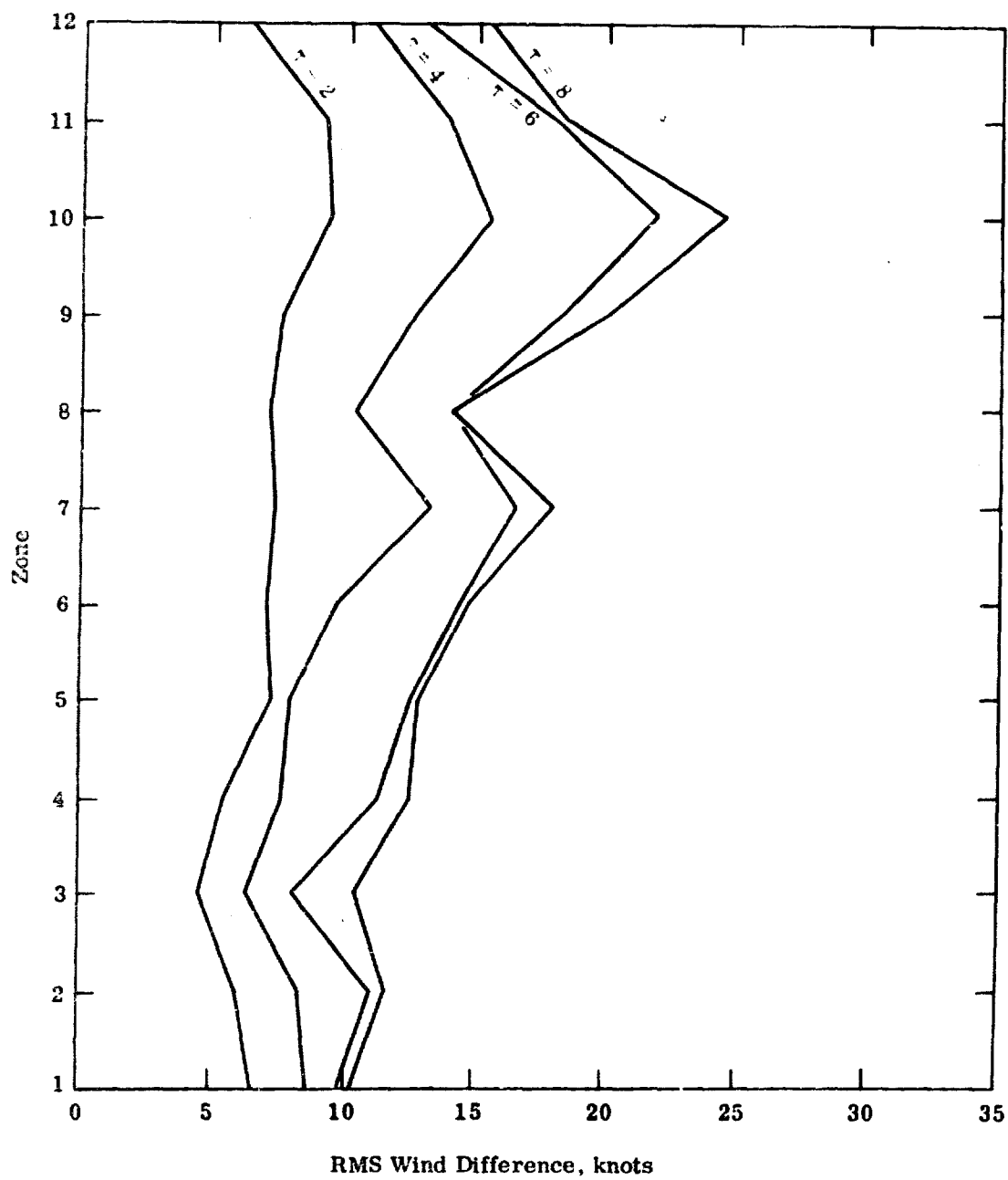
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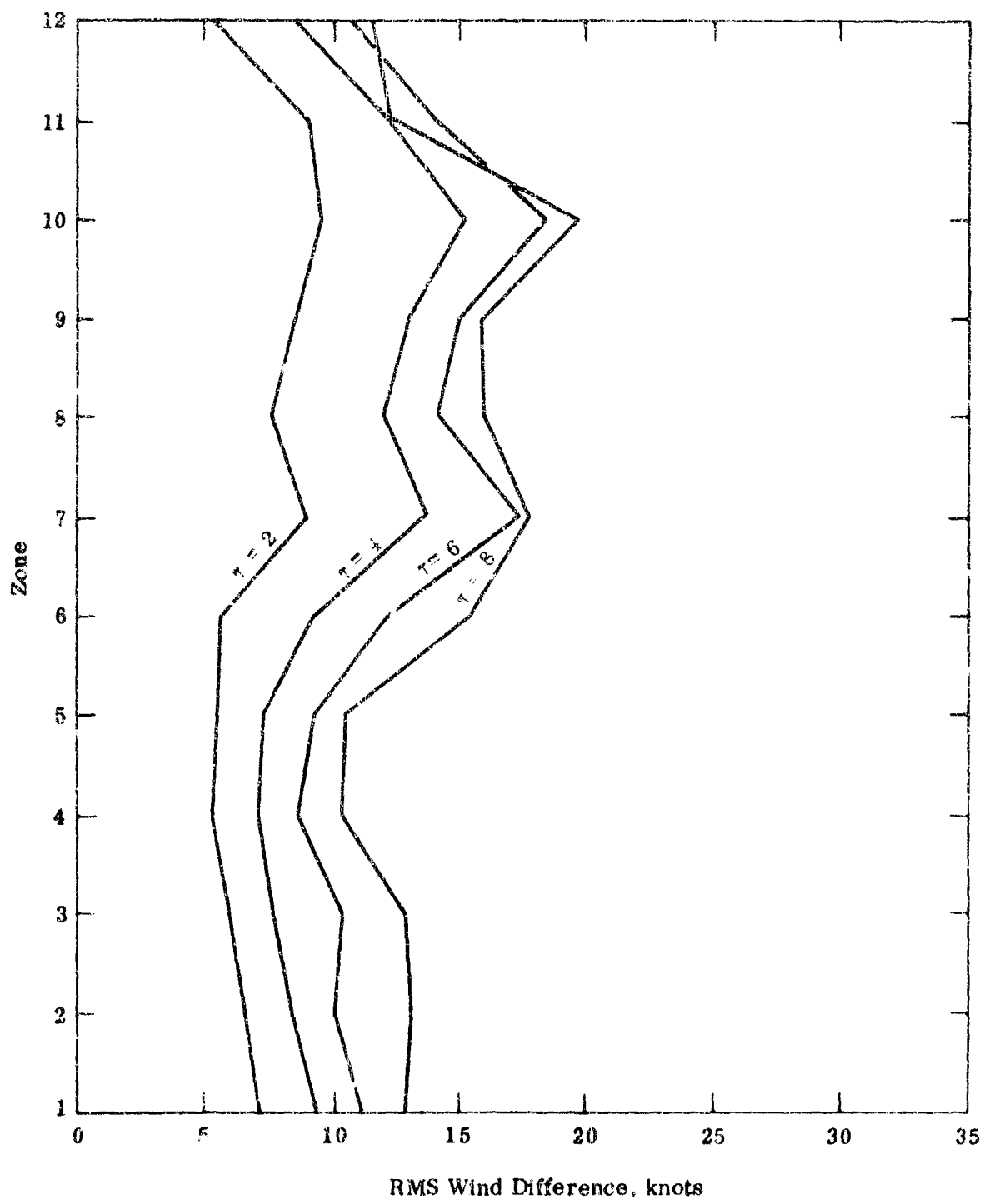
Fig. 3. Time variability. Benson.

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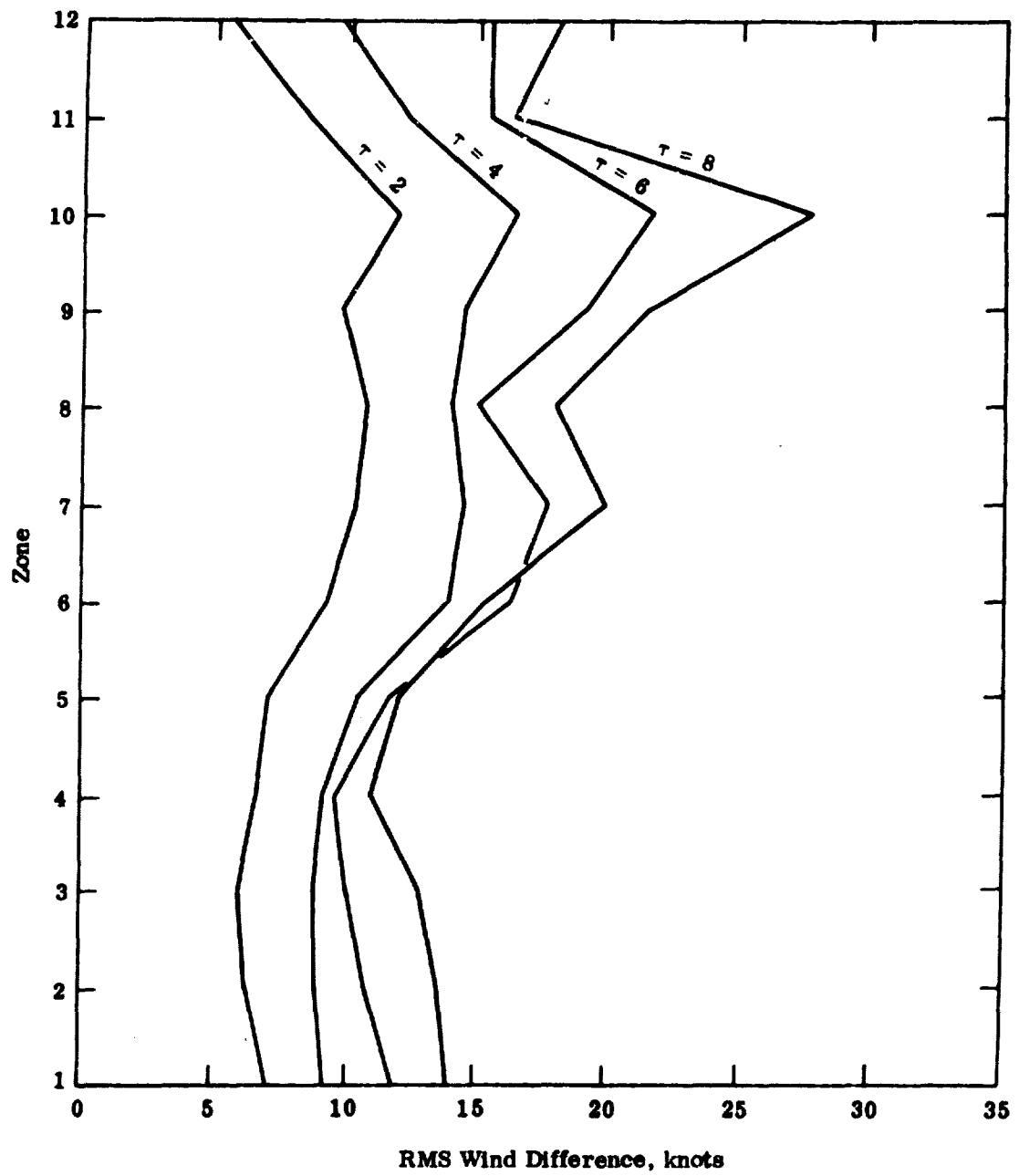Fig. 4. Time variability, Bisbee Junction.
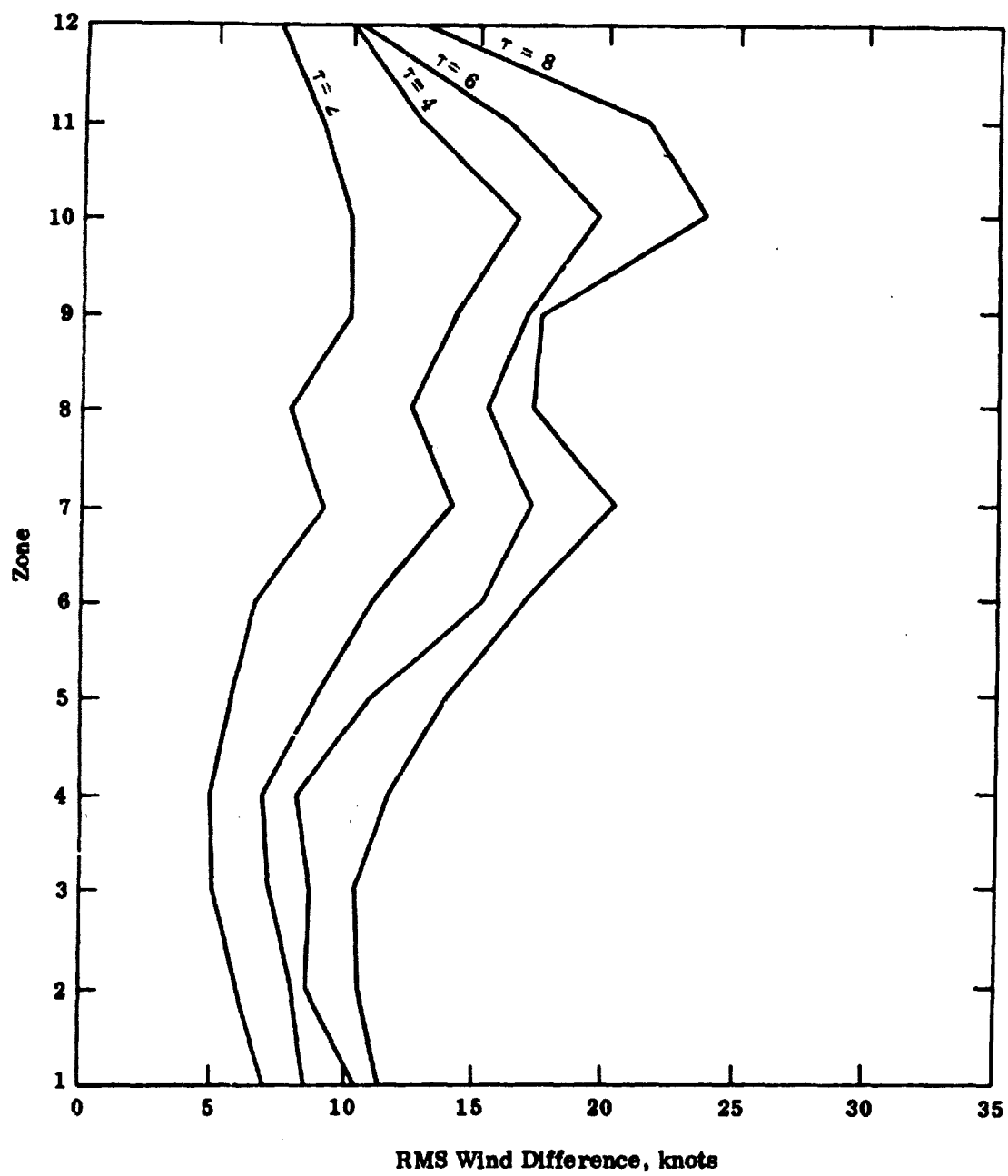
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Fig. 5.  Time variability. Douglas.
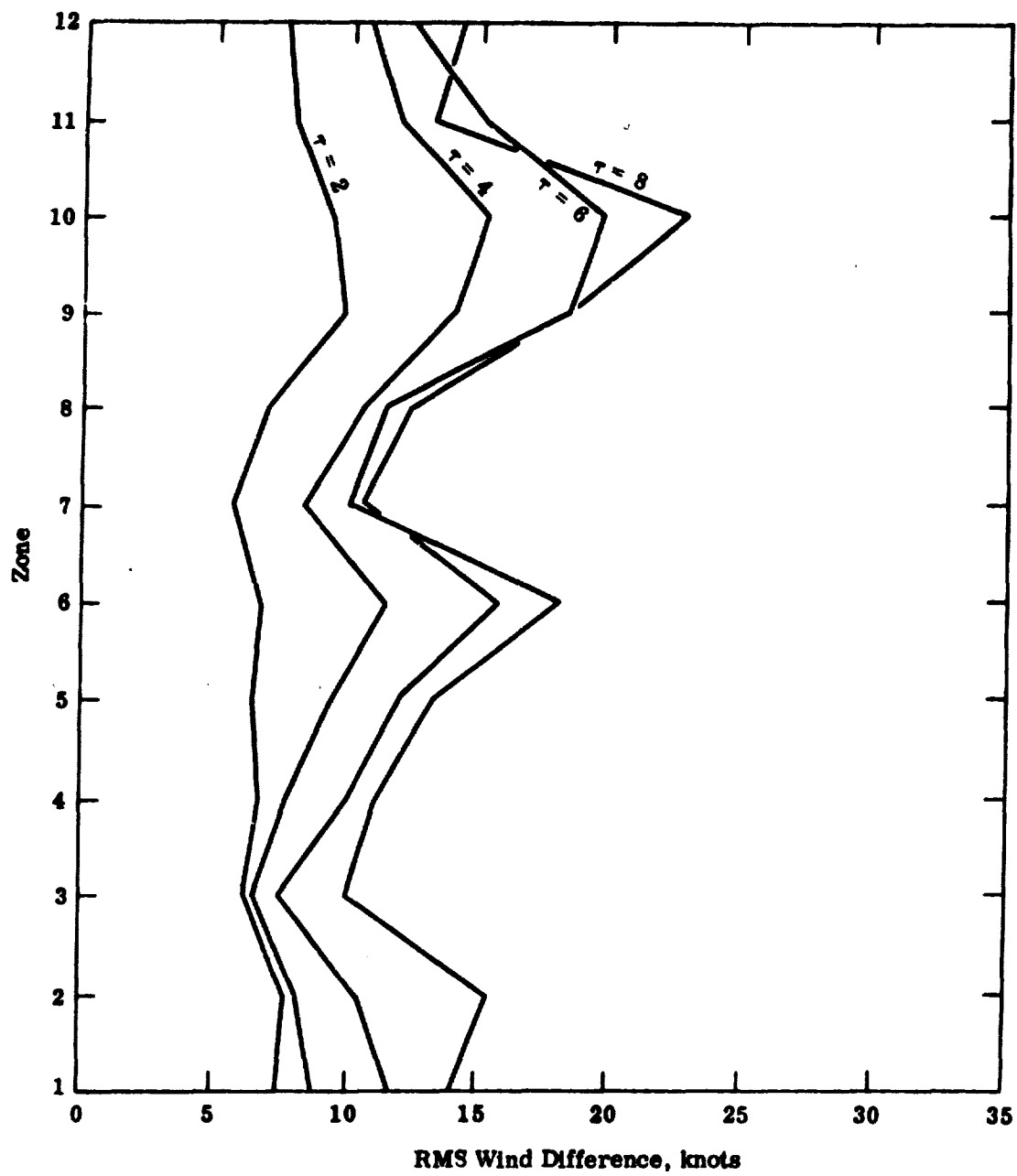
Fig. 6. Time variability, Fairbanks.

Fig. 7. Time variability, Hereford.
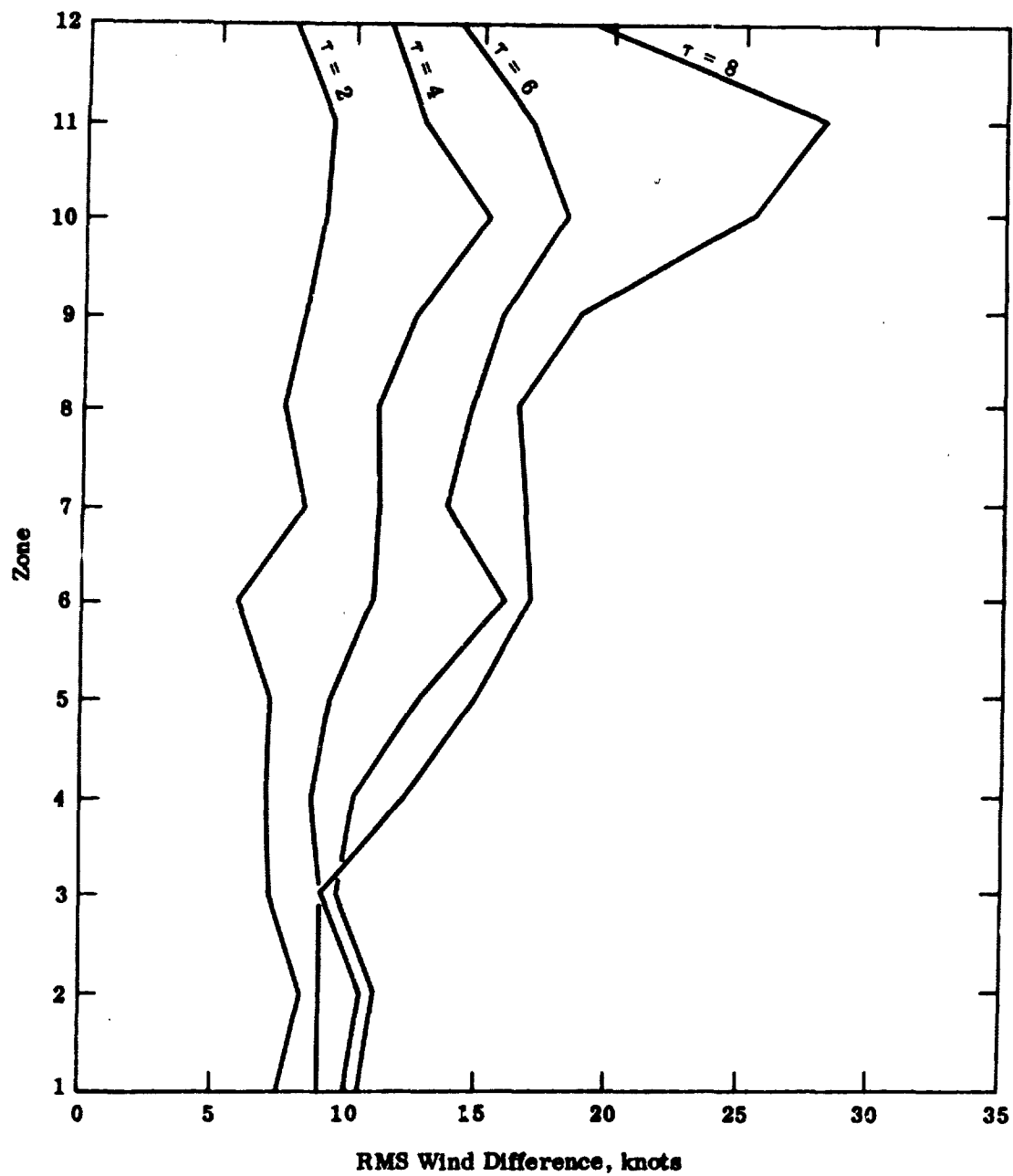
Fig. 8. Time variability, Ft. Huachuca.
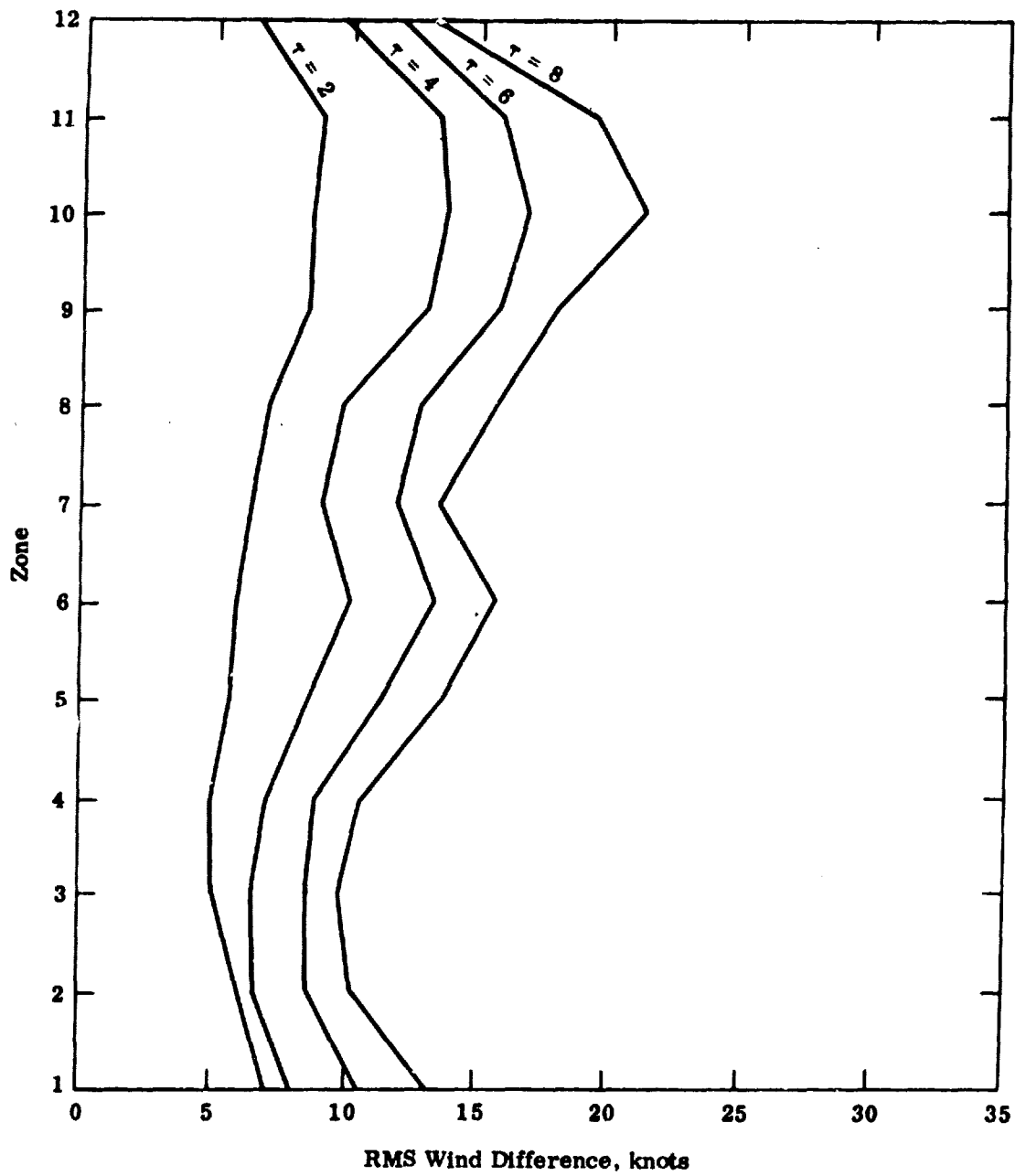
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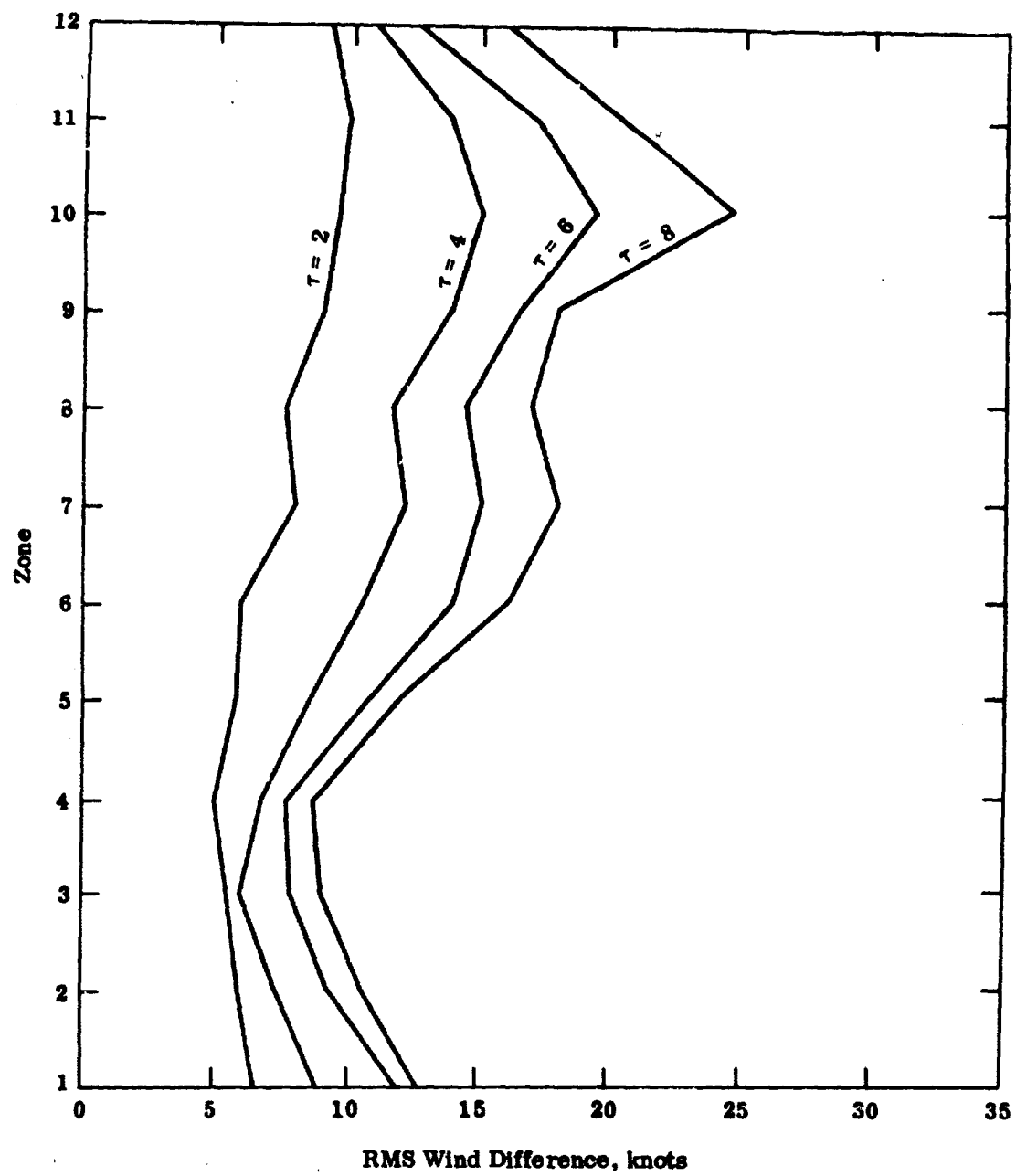
Fig. 9. Time variability, Nogales.

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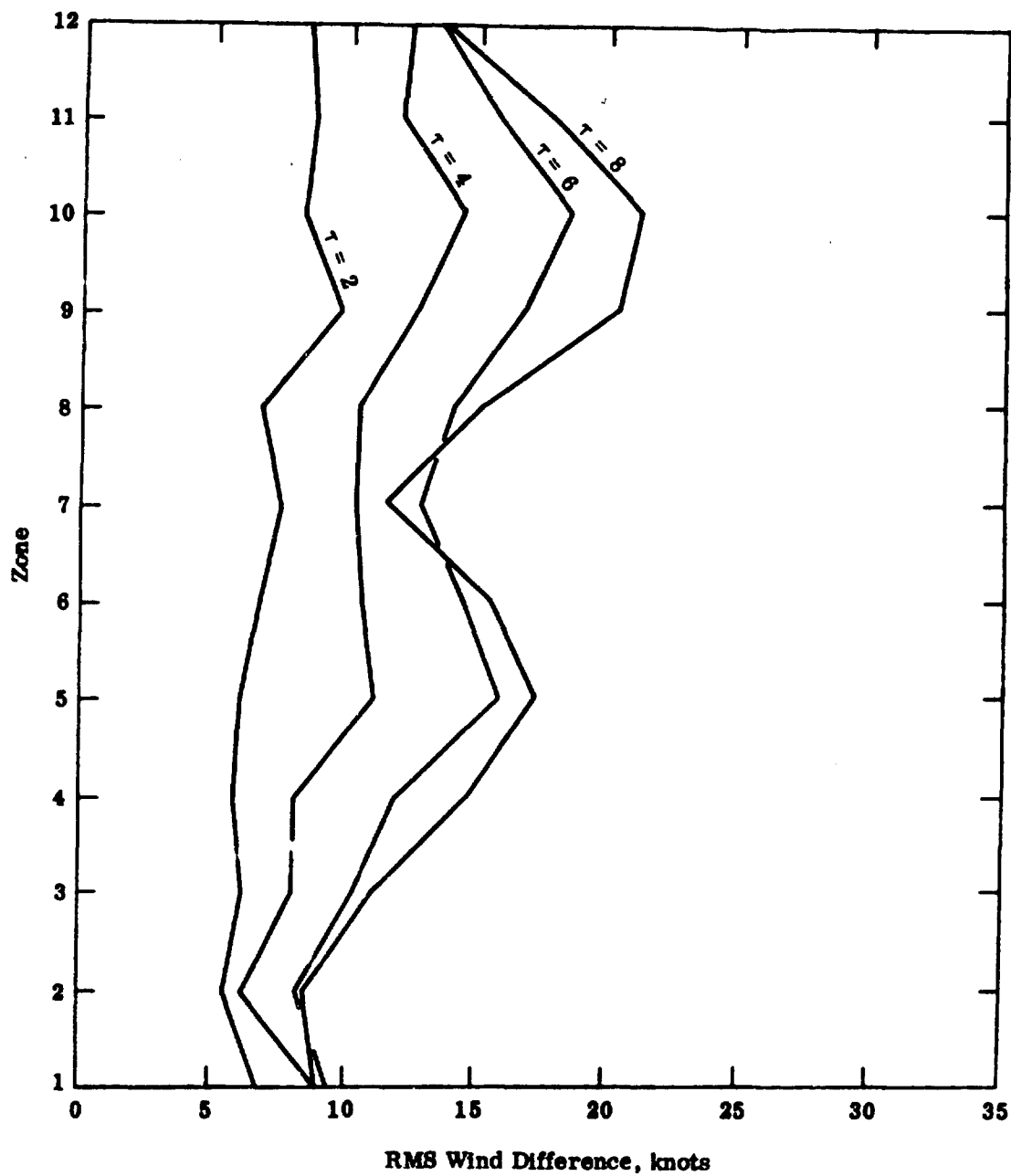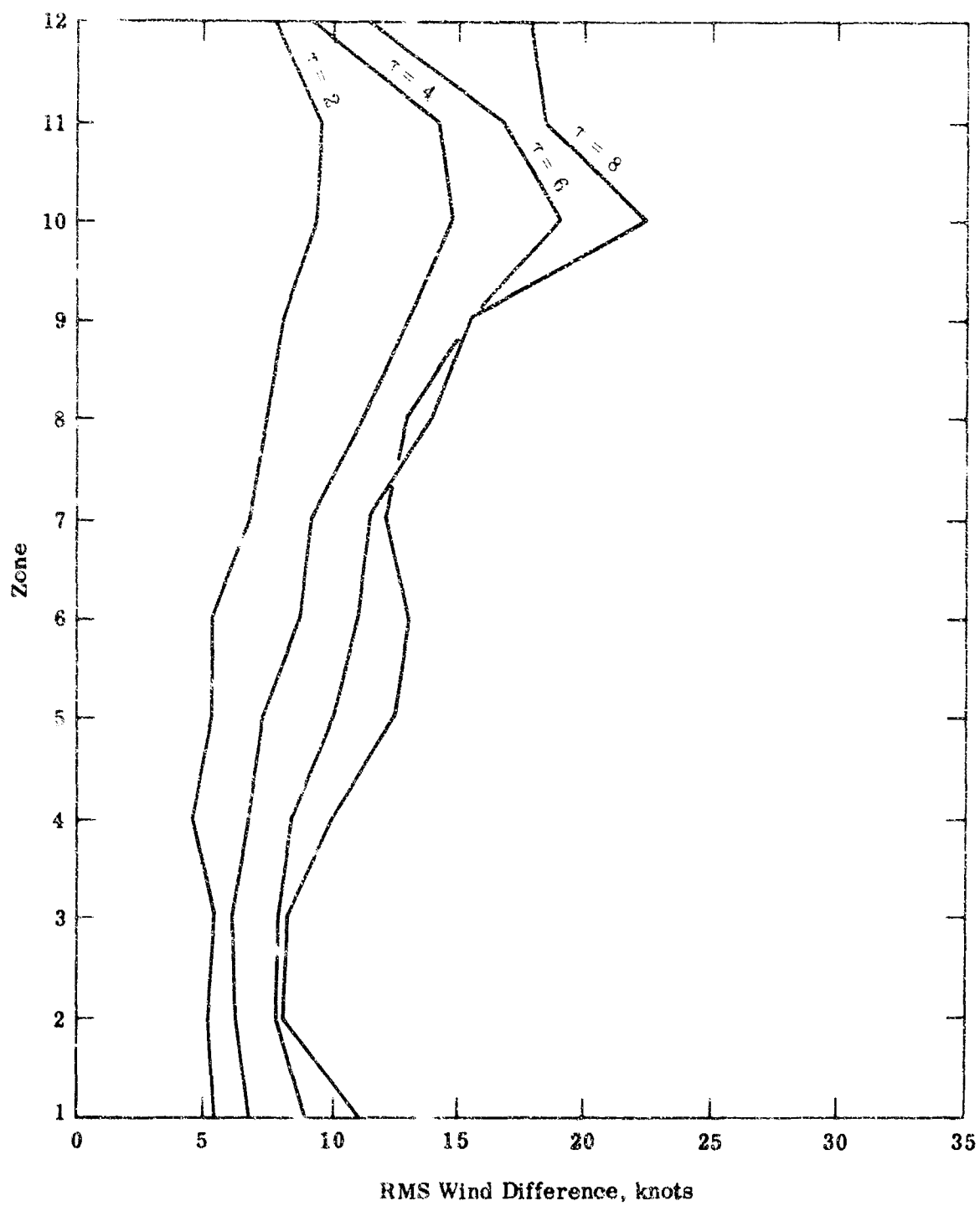Fig. 10. Time variability, Patagonia.

Fig. 11. Time variability, Parker Canyon.

Fig. 12. Time variability, Sonoita.

Fig. 13. Time variability, Tombstone.
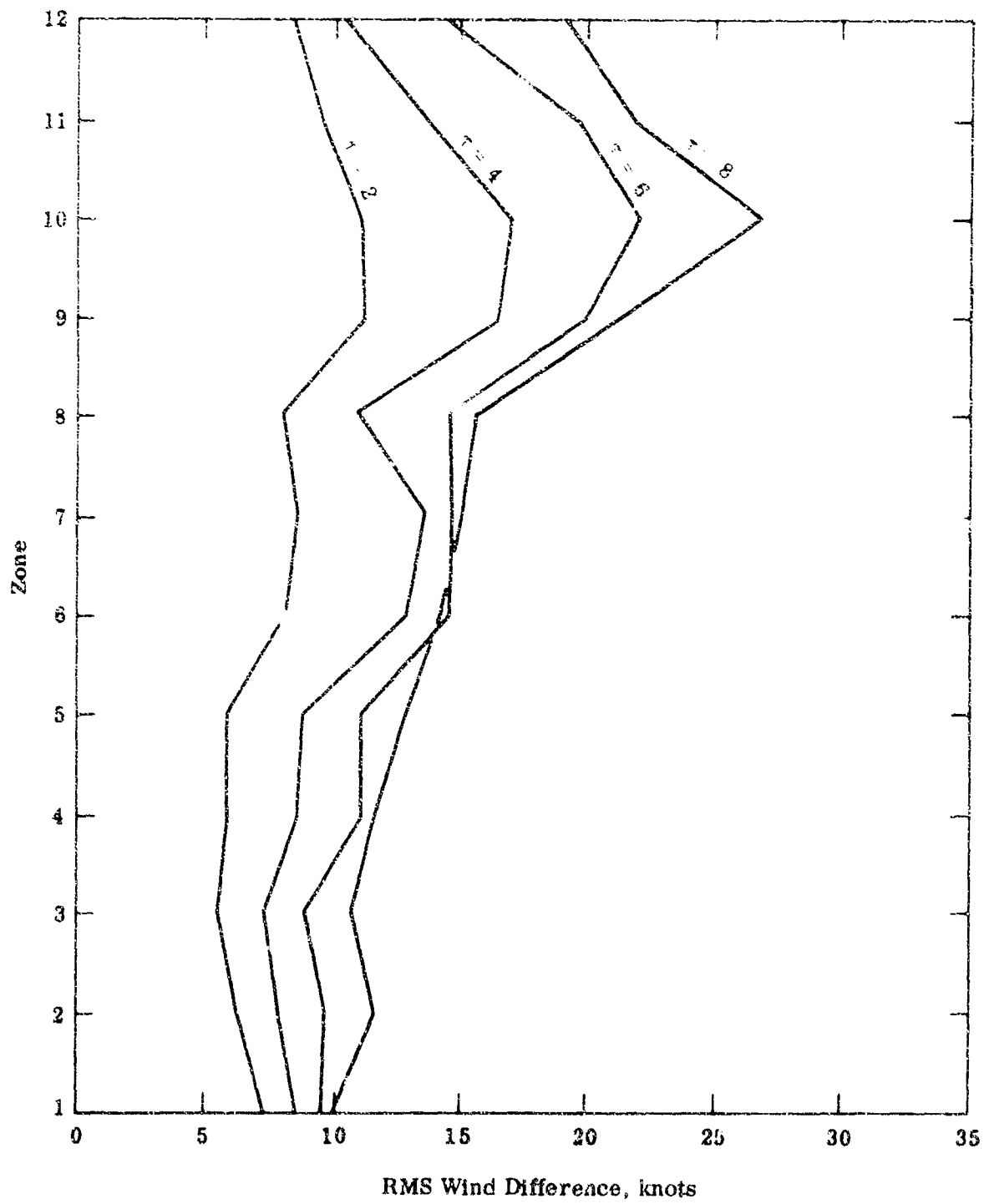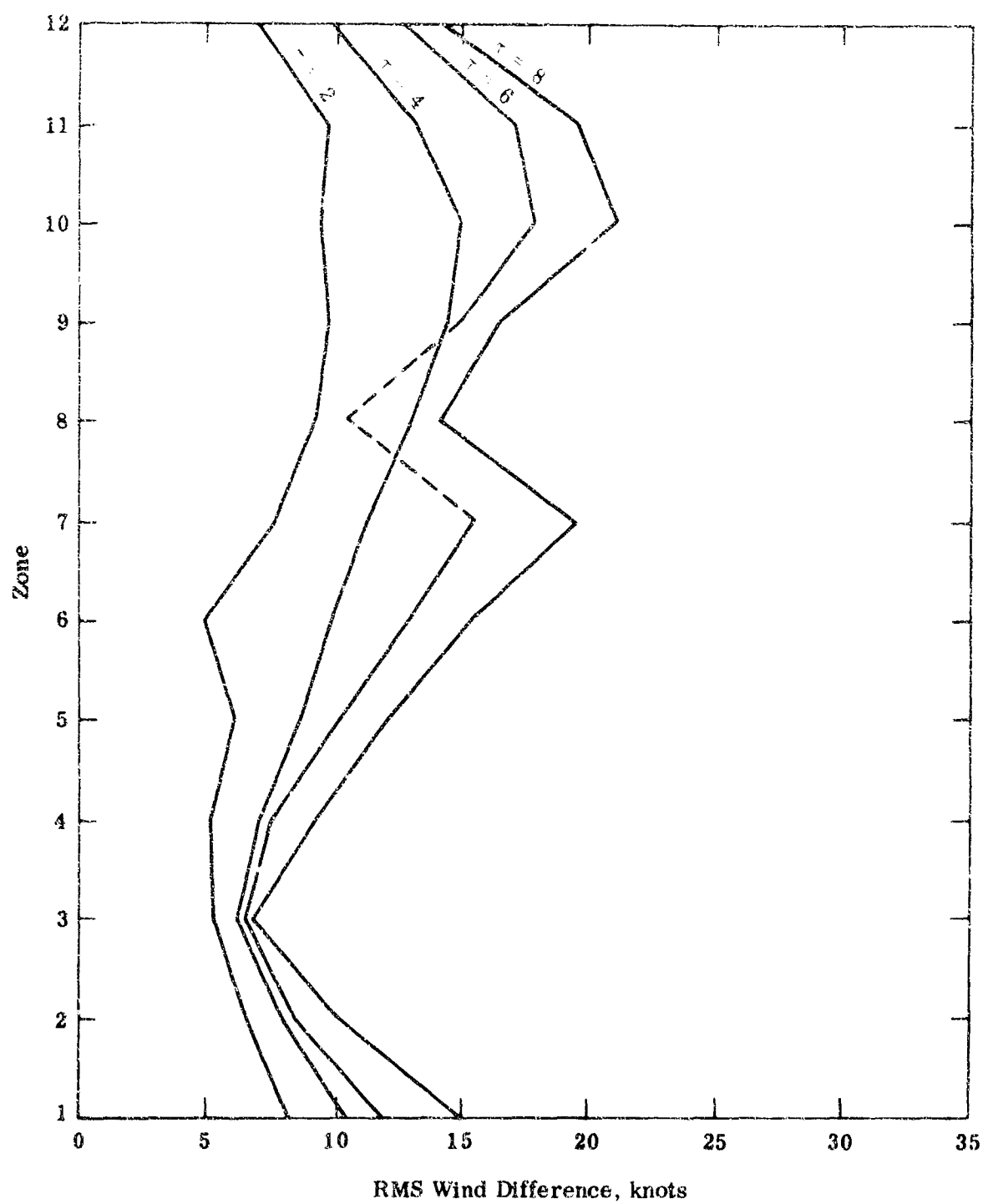
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Fig. 14. Time variability. Wilcox.

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| Space Variability of Ballistic Winds | | | | | | |
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